DEFENCE R&D DÉFENSE

Further Examination of Iridium Satellite Phone and Pager System for Military Use

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Defence Research Establishment Ottawa

Defence R&D Canada

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 2000-084
January 2000

National Defence Défense nationale

Canada

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5CA14

ABSTRACT

The Iridium satellite-based personal communications system (PCS) has been offering voice and messaging services since November 1998 and March 1999 respectively. With its interconnected constellation of 66 low earth orbit (LEO) satellites, Iridium is capable of providing continuous communications anywhere in the world. This Technical Memorandum describes further evaluations of the Iridium system carried out by the Military Satellite Communications group at Defence Research Establishment Ottawa (DREO). Evaluations include additional voice service test at high latitudes, voice service tests with an Airsat1 terminal, messaging service evaluation, three-way conference calling over Iridium, and propagation delay tests over the voice circuit.

RÉSUMÉ

Le système de communications personnelles par satellites Iridium offre un service de communication vocale depuis novembre 1998 et de messagerie depuis mars 1999. Avec sa constellation interconnectée de 66 satellites sur orbites terrestres basses, Iridium permet des communications partout dans le monde. Ce mémorandum technique décrit de nouvelles études d'évaluation du système Iridium entreprises par le groupe 'Communications militaires par satellites' du Centre de recherches pour la défense, Ottawa (CRDO). Les évaluations ont porté sur des tests additionnels du service téléphonique à hautes latitudes, sur des tests du service téléphonique avec un terminal Airsat 1, sur l'évaluation du service de messagerie et d'appels conférence à trois avec Iridium, et sur des tests de temps de propagation pour le circuit téléphonique.

EXECUTIVE SUMMARY

Background

The Iridium system is a satellite-based personal communications system (PCS) consisting of a constellation of 66 low earth orbit (LEO) satellites connected by intersatellite links (ISL), a number of gateway stations situated around the world, handheld terminals comparable in size to medium-sized cellular phones, and pagers. Voice and messaging services have been available since November 1998 and March 1999 respectively.

The Military Satellite Communications Group at Defence Research Establishment Ottawa (DREO) purchased Iridium satellite phones and pagers and have been evaluating the voice and messaging services to assess its potential for use by the military. Initial evaluations were documented in [3] and [4]. This Technical Memorandum describes further testing carried out including tests with mobile communications platforms at high latitudes, three-way conferencing, messaging, and propagation delay tests.

Results

Voice service tests of the Iridium system at high latitudes as well as with the Airsat1 terminal were consistent with initial evaluations. Users observed that good quality links with little distortion were maintained for extended periods of time with few dropped calls. Voice intelligibility was good once users became accustomed to the propagation delay. Again, a slight degradation in intelligibility was noted when there was a female speaker. Calls were also successfully established between the Airsat1 terminal and InmarsatB terminal, as well as between the Airsat1 and a Rapid Response Communications Package (RRCP) terminal operating over Intelsat. Interoperability of these systems is considered to be an asset for the Canadian Forces who currently have Inmarsat and RRCP terminals in their inventory.

Multiple users can be connected over Iridium by the conferencing feature. Three-way conferencing was successfully demonstrated between a public switch telephone network (PSTN) unit and two Iridium satellite phones. Iridium offers a conferencing capability for up to four parties using their world calling card.

Propagation delays measured for the PSTN-Iridium connection were generally between 450ms and 500ms long. Iridium-Iridium links exhibited propagation delays of between 200ms and 350ms. It is noted that for the Iridium-Iridium connection, the two Iridium phones were co-located. Hence, the propagation delay would be measured for a signal transmitted to a satellite passing overhead and directly relayed back to the receiving unit. Conversely, in a PSTN-Iridium scenario, the transmitted signal would be routed to the gateway via ISLs and forwarded through the PSTN infrastructure. Also, vocoder processing can contribute up to 100ms of delay.

As a feature of the messaging service, a user can select whether text messages and voice mail notifications are delivered to the pager, phone, or both when the phone and pager are bundled. This feature was tested and verified to be operating properly. With this feature, a user can conserve the battery of the phone by choosing to have all messages delivered to the pager, and only activating the phone when they need to place a call. "Follow-me" messaging is another feature of the messaging service that was verified for a bundled phone and pager. With "Follow-me" messaging, a user can automatically update the message delivery area (MDA) of the pager by turning the associated phone on to re-register on the network.

Significance

The results from the evaluations of the Iridium system show that the potential for military application of the Iridium satellite phone is positive. Remotely located installations or locations where no other communications system is available would benefit from the ability of the Iridium system to provide a global communications capability. Interoperability with other communications systems employed in the Canadian Forces is an asset. Messaging and conference calling features of the system provide flexibility in reaching users.

Future Plans

Future evaluations of the Iridium system may include propagation delay tests for calls covering longer distances to examine effects of intersatellite and intergateway routing of the call.

Tom, C., Lambert, J.D., Further Examination of Iridium Satellite Phone and Pager System for Military Use, Defence Research Establishment Ottawa, DREO TM 2000-084, January 2000

SOMMAIRE

Contexte

Le système de communications personnelles par satellites Iridium est constitué d'une constellation de 66 satellites sur orbites terrestres basses équipés de liaisons intersatellites (LIS), d'un ensemble de stations-passerelles distribuées partout dans le monde, de terminaux portatifs (dont la taille est comparable aux téléphones cellulaires de dimensions moyennes), et de récepteurs de radiomessagerie. Le service téléphonique est disponible depuis novembre 1998 et celui de messagerie depuis mars 1999.

Le groupe 'Communications militaires par satellites' du Centre de recherches pour la défense, Ottawa, a acheté des téléphones et des récepteurs de radiomessagerie pour satellites Iridium afin d'évaluer l'utilité des services téléphoniques et de messagerie de ce système pour les Forces canadiennes. Les premières évaluations ont été décrites dans les références [3] et [4]. Ici nous présentons les résultats de nouveaux essais sur la performance du système Iridium avec des unités de communications mobiles déployées à hautes latitudes, sur les services de conférence à trois et de messagerie, et sur les temps de propagation.

Résultats

Les essais à hautes latitudes du service téléphonique du système Iridium, de même que ceux avec le terminal Airsat 1, ont été compatibles avec les résultats antérieurs. Les utilisateurs ont observé que des liaisons de bonne qualité ont pu être maintenues pendant de longues périodes de temps avec peu d'appels interrompus. L'intelligibilité de la voix était bonne après que les utilisateurs se furent habitués au temps mort causé par le temps de propagation. Comme précédemment, on a remarqué une faible détérioration de l'intelligibilité de la voix féminine. On a aussi réussi à effectuer des appels entre un terminal Airsat 1 et un terminal Inmarsat B, de même qu'entre un terminal Airsat 1 et un terminal du système de communications de réponse rapide (Rapid Response Communications Package - RRCP) utilisant Intelsat. L'interopérabilité de ces systèmes est considérée comme un avantage pour les Forces canadiennes qui comptent les terminaux Inmarsat et RRCP dans leur inventaire courant.

Plusieurs utilisateurs peuvent être interreliés par Iridium grâce à sa fonction d'appel conférence. La fonction de conférence à trois a été mise en évidence avec une unité de réseau téléphonique public commuté (RTPC) et deux téléphones pour satellites Iridium. Avec leur carte d'appel mondial, jusqu'à quatre abonnés peuvent utiliser la fonction d'appel conférence d'Iridium.

Les temps de propagation mesurés pour les liaisons RTPC-Iridium se situaient généralement entre 450ms et 500ms. Les liaisons Iridium-Iridium avaient des temps de propagation entre 200ms et 350ms. Il faut signaler que, pour la liaison Iridium-Iridium, les deux

appareils téléphoniques Iridium étaient au même endroit. Dans ce cas-là, on mesurait le temps de propagation d'un signal transmis à un satellite survolant directement le site et immédiatement retransmis à l'unité réceptrice, alors que, dans le cas RTPC-Iridium, le signal émis était acheminé à une station-passerelle via des LISs et transmis par l'entremise de l'infrastructure du RTPC. De plus, le traitement de signal du vocodeur pouvait ajouter jusqu'à 100ms de délai.

Une fonction du service de messagerie permet à l'abonné de choisir si l'annonce de l'arrivée de messages en texte et de messagerie vocale doit être transmise au récepteur de radiomessagerie, au téléphone, ou aux deux à la fois, s'ils sont intégrés. On a testé et vérifié que cette caractéristique fonctionnait correctement. De plus, elle permet à l'utilisateur d'économiser l'énergie de la pile de l'appareil en choisissant de faire suivre tous les messages au récepteur de radiomessagerie et de n'activer le téléphone lui-même que lorsqu'il doit faire un appel. La messagerie à téléprogrammation successive est une autre fonction du service de messagerie qui a été vérifiée avec un appareil intègrant téléphone et récepteur de radiomessagerie. Avec cette fonction, l'utilisateur peut automatiquement mettre à jour le secteur géographique de réception des messages du récepteur de radiomessagerie en mettant en marche le téléphone associé pour se réinscrire au réseau.

Impact

Les résultats de ce groupe d'évaluation montrent que le système de téléphonie Iridium offre un potentiel positif pour des applications militaires. Les installations en régions éloignées ou les localités qui n'ont pas accès à d'autres moyens de communications peuvent bénéficier de la capacité du système Iridium de fournir des communications au niveau mondial. L'interopérabilité avec les autres systèmes de communications utilisés par les Forces canadiennes constitue un avantage. Les fonctions de messagerie et d'appels conférence offrent une plus grande flexibilité pour entrer en contact avec les usagers.

Plans futurs

Les futures évaluations du système Iridium pourraient étudier l'impact de l'acheminement intersatellites et interpasserelles sur le temps de propagation d'appels couvrant de plus grandes distances.

Tom, C., Lambert, J.D., Nouvelles études d'évaluation du système de téléphones et de récepteurs de radiomessagerie pour satellites Iridium, Le Centre de recherches pour la défense Ottawa, DREO TM 2000-084, janvier 2000. (en anglais)

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS AND ABBREVIATIONS

CFB	Canadian Forces Base
CP140	Canadian Aurora P3
DAMA	Demand Assigned Multiple Access
DREO	Defence Research Establishment Ottawa
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communications
ISL	InterSatellite Link
ISU	Iridium Subscriber Unit
LEO	Low Earth Orbit
MDA	Message Delivery Area
MRT	Modified Rhyme Test
PCS	Personal Communications System
pps	Pulse Per Second
PSTN	Public Switch Telephone Network
QPSK	Quadrature Phase Shift Keying
RRCP	Rapid Response Communications Package
TES	Telephony Earth Station
TDMA	Time Division Multiple Access

1.0 Introduction

1.1 General

The demand for personal communications services has seen phenomenal growth over the past decade. Terrestrial-based cellular service were first offered to populated areas in developed countries. However, expansion of such services to remote areas or to areas without existing telecommunications infrastructure (e.g. Third World countries) is progressing rapidly. In addition, extending personal communications services with handheld terminals to offer truly global communications capability is an attractive feature for mobile users and has prompted the development of satellite-based personal communications systems (PCS).

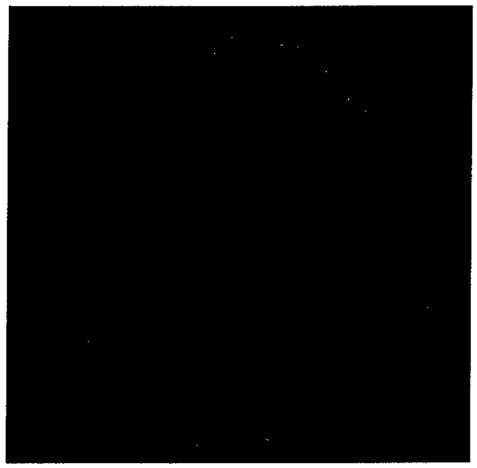
Satellite-based PCSs operate conceptually in the same manner as terrestrial-based cellular PCSs. Base stations which relay transmissions are provided by a constellation of orbiting satellites as opposed to ground-based towers in terrestrial-based PCSs. The design of the satellite and satellite constellation is such that at least one satellite is always in view of the handset or user. Whereas linkages back to central hubs extend the reach capability of ground-based base stations, the nature of orbiting satellites inherently provides greater reach capability. Furthermore, satellites may be connected by intersatellite links (ISLs) to route traffic over long distances. A challenge for satellite-based PCSs is that they are still a line-of-sight technology. With the greater distance between the user and the satellite base station, a balance must be maintained between the need for higher link margins and the desire for smaller handheld units that are available with terrestrial-based cellular systems. For satellite-based PCSs the compromise consists of a handheld unit, comparable to a medium-size cellular phone, with slightly degraded performance inside buildings and in areas obstructed by terrain or foliage.

1.2 The Iridium System

1.2.1 General Description

The Iridium system is designed to provide global personal communications via an interconnected constellation of low earth orbit (LEO) satellites communicating directly with handheld terminals. The system provides communications to all parts of the globe, including the polar regions. The Iridium constellation consists of 66 satellites in 6 near polar orbits of 11 satellites at an altitude of 780 km as shown in Fig. 1. Each satellite projects 48 beams of approximately 70 km diameter each on the surface of the earth, with a total footprint of approximately 4,700 km diameter. The constellation was selected to provide overlapping footprints at the equator to support continuous coverage and transparent hand-off between satellites. As a consequence, the overlap increases as the satellites approach the poles.

The Iridium satellite is a processing satellite based upon global system for mobile communications (GSM) technology. This allows the handset to directly communicate to the satellite and to pass data independently of terrestrial gateways. Iridium is the only system that provides communications between two satellite handsets without being downlinked through a terrestrial gateway. The Iridium system uses 1616 MHz to 1626.5 MHz to provide communications between the handset and satellite for telephone and messaging services. The links use frequency division multiple access (FDMA) and time division multiple access (TDMA) to separate users, and uplink and downlink communications. The waveform employs quadrature phase shift keying (QPSK). Each satellite is linked to four other satellites (one behind, one ahead, and one in each adjacent orbit) by four separate inter-satellite links. This allows users to be handed off between satellites as they pass overhead and allows communication traffic to be routed to the closest satellite before being downlinked.

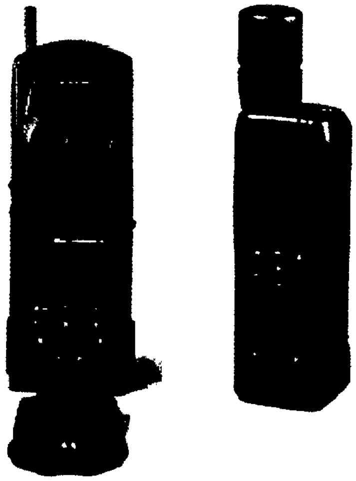


(graphic from [1])

Fig. 1 The Iridium constellation.

Initial voice service commenced in November 1998, followed by paging service in March 1999. The planned release date for data service at 2400 b/s was to be late 1999. However, it appears that the data service release has been delayed. There are currently two manufacturers of the Iridium satellite phone, also referred to as the Iridium subscriber unit (ISU). Pictures of the Motorola and Kyocera Iridium phones are shown in Fig. 2. The Motorola phone is shown on the left of Fig. 2 with a cellular cassette and antenna mounted. The Kyocera phone is shown with the satellite phone antenna installed. They are comparable in size and weight to existing medium sized cellular phones. Depending on the batteries used, the phones can communicate continuously from 2 to 6 hours or operate on standby from 16 to 60 hours. Call rates are currently listed as $2.50 Cdn per minute for domestic calls, and $4.50 Cdn per minute for international calls.

In addition to the phones, pagers are also available to be used on the Iridium system. A Motorola pager is shown in Fig. 3. A monthly network access fee is charged for the pager with the price depending on whether the pager is operated as a standalone device or is linked with the Iridium satellite phone using the "Follow-me" messaging service.



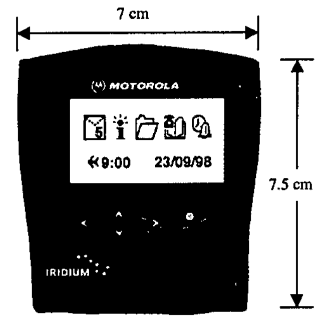
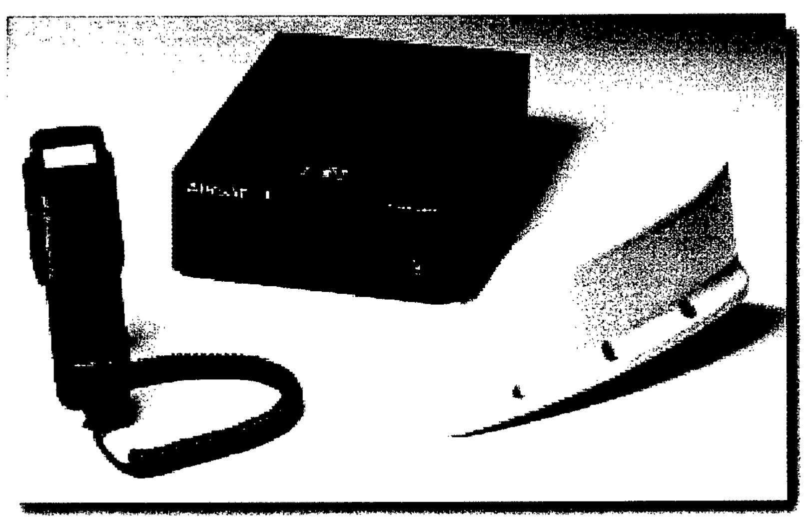


Fig. 2 Motorola's Iridium satellite phone (left) and Kyocera's satellite phone (right)

Fig. 3 Motorola's Iridium pager.

1.2.2 AIRSAT1 Terminal General Description

The Airsat1 terminal is a single channel satellite communications unit that was developed by AlliedSignal and which uses the Iridium global mobile satellite system. The Airsat1 terminal is intended for use on light aircraft. The Airsat1 terminal consists of a transceiver unit, digital handset, and a low-gain, blade antenna as shown in Fig. 4. The Airsat1 terminal operates in exactly the same manner as an ISU. The Airsat1 terminal is identified by a 12-digit number and supports two-way voice calls, voice mail, messaging, and standard Iridium subscriber services. More information on the Airsat1 terminal can be found in [2].



(photo from [2])

Fig. 4 AlliedSignal Airsat1 terminal.

1.2.3 Messaging Options

In addition to a voice service, Iridium also provides a text messaging or paging service to customers. As described in [3], text messages of up to 120 characters can be sent to the pager or the phone. The user is able to select where text messages are delivered when a satellite phone and pager are linked together or "bundled". The service provider programs the bundling of the phone and pager. The selection of where text messages are delivered is done via the "*Message Destination*" option. The user can select to have text messages delivered to the phone, the pager, or both.

There is an additional user option called "*Notification Destination*". The notification destination indicates where notification of a voice mail is to be delivered. As with the message destination, notification destination can be set to the phone, pager, or both. The user can also opt to disable message notification.

The "Follow-me" messaging feature of the Iridium system is an additional service provided by Iridium. In order for "Follow-me" messaging to work, the satellite phone and pager must be bundled. "Follow-me" messaging allows for the Message Delivery Area (MDA) of a pager to be automatically updated by re-registering the satellite phone in the new location. When the user has activated "Follow-me" messaging, text messages addressed to the pager are delivered to the message delivery area (MDA) where the phone was last registered. Thus, when the phone and pager are bundled, they must also be located within the same coverage area in order for the pager to receive text messages.

An advantage of the "Follow-me" feature for a mobile user is that he is not required to know what MDA to set in order to receive text messages. A user has only to turn the associated or bundled phone on and register on the Iridium network to automatically have the MDA of the user's current location override the active MDAs selected for the pager.

1.2.3.1 Specifying Message Destination and Notification Destination

The following table describes the procedure for selecting the message and notification destinations for a bundled phone and pager. In this example, the phone and pager are set up so that text messages are delivered to the pager and notification of voice mail messages are delivered to both the pager and the phone. Further details of user options menus are provided in the Iridium user's guide which is available on the Iridium website [1]. A subset of the menus is shown in Appendix A.

STEP 1	Call satellite messaging centre (1-888-588-2456) or satellite phone number
STEP 2	Enter satellite phone number again if prompted
STEP 3	Press <*>
STEP 4	Enter password
STEP 5	Press <4> for Personal options
STEP 6	Press <3> for Notification options[x]
STEP 7	Press <6> for Notification Destination
STEP 8	Press <3> for notification of voice mail to be delivered to both the phone and pager
STEP 9	Press <*> twice to go back two levels in menu
STEP 10	Press <6> for Message Destination
STEP 11	Press <1> for text messages to be delivered to the pager
STEP 12	Press <*> twice to go back two levels in menu
STEP 13	Press <#> to exit

[x] Ensure that message notification is enabled by listening to options in Notifications options menu. If prompted to press <3> to disable message notification, then message notification has been enabled. Otherwise, press <3> to enable message notification.

Table 1 Procedure for selecting message and notification destinations for the Iridium satellite phone and pager

1.2.3.2 Automatic "Follow-me" messaging

The following table describes the procedure for activating and de-activating "Follow-me" messaging for the bundled phone and pager. It is assumed that the service provider has already programmed the bundling of the phone and pager. The steps described in the table can be traced in Appendix A which contains a copy of part of the user option menus for the Iridium system.

STEP 1	Call satellite messaging centre (1-888-588-2456) or satellite phone number
STEP 2	Enter satellite phone number again if prompted
STEP 3	Press <*>
STEP 4	Enter password
STEP 5	Press <4> for Personal options
STEP 6	Press <3> for Notification options
STEP 7	Press <1> to either activate or de-activate "Follow-me" messaging
STEP 8	Press <*> twice to go back two levels in menu
STEP 9	Press <#> to exit

Table 2 Procedure for activating and de-activating "Follow-me" messaging for the Iridium satellite phone and pager

1.3 Outline of Technical Memorandum

This Technical Memorandum describes further trials carried out on the Iridium voice and message services. In particular, trials of features that may have military application, voice service at high latitudes, and service with mobile platforms are investigated. Section 2 describes each of the scenarios that were examined. Results of the trials are presented in Section 3 as well as any observations of the voice and messaging service. Finally, Section 4 consists of general conclusions of the service and its utility for military applications.

2.0 Description of Iridium Satellite Phone and Pager Tests

2.1 Iridium Satellite Phone Tests

2.1.1 ISU to ISU and Airsat1 at Northern Latitudes

2.1.1.1 Objective

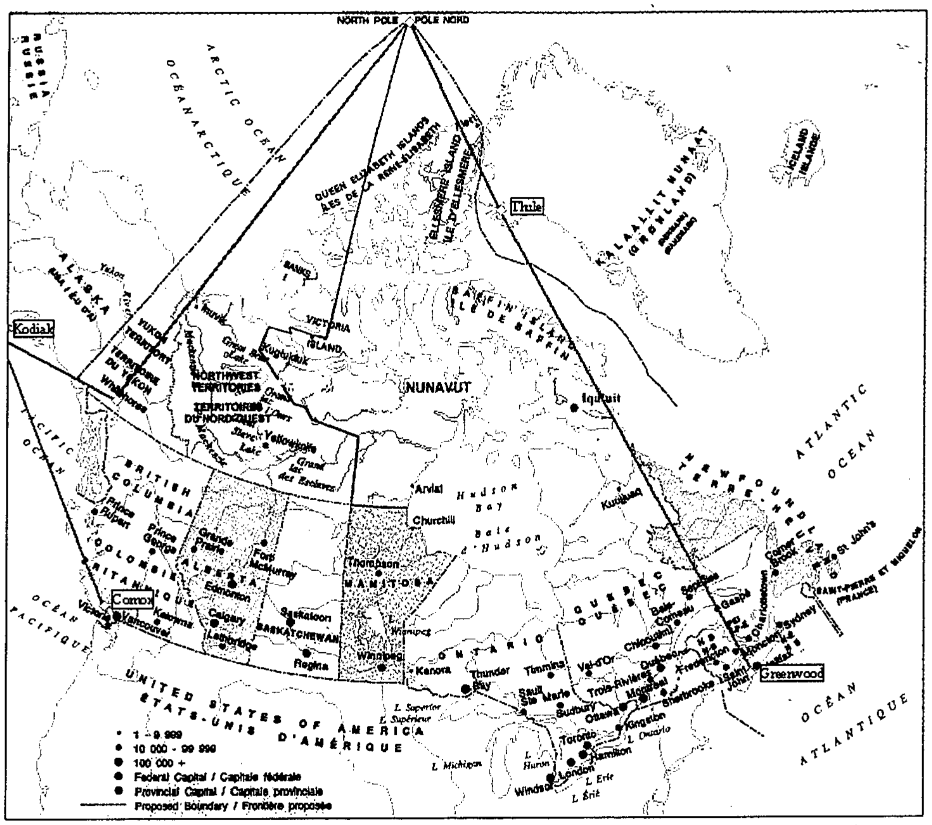
The objective of this test was to examine the voice service of the Iridium satellite phone system at high latitudes. As well, communications with an Iridium Airsat1 terminal installed onboard a Canadian Aurora P3 (CP140) plane which flew missions to northern latitudes was trialed.

2.1.1.2 Test Method

For the Iridium satellite phone test at high latitudes, calls were made between DREO and CFB Alert. Both ISU to Public Switch Telephone Network (PSTN) and ISU to ISU combinations were examined. A subjective evaluation is recorded noting general link quality and voice intelligibility. As in [4], abbreviated Modified Rhyme Tests (MRTs) were performed to evaluate voice intelligibility. The caller read a pre-defined list of words and the callee recorded what they heard. The test was repeated in the other direction with the callee reading a pre-defined list of words.

For the voice service evaluation with the Airsat1 terminal, an Airsat1 terminal was installed aboard a Canadian Aurora P3 (CP140). The CP140 carried out two Northern Patrols during which calls were made to and from the Airsat1 terminal. The first mission took place 22-25 June 1999. The second mission was flown 13-17 July 1999. Due to aircraft mechanical problems, the first mission was aborted shortly after take off. Fig. 5. shows the flight plan for the mission carried out between 13 and 17 July 1999. Calls were established at various times during the flight between the Airsat1 terminal and PSTN in Ottawa, as well as between the Airsat1 terminal and an Iridium ISU also located at DREO. Again, the abbreviated MRTs were performed for each combination and in both directions to evaluate voice intelligibility.

In addition to the voice tests, text messages were sent by email to the Airsat1 terminal. The email address of the Airsat1 terminal was 881631034020@iridium.com .



(Map from www.gc.ca)

— CP140 flight path

Fig. 5 Canadian CP140 Northern Patrol Flight Plan 13-17 July 1999.

2.1.2 Additional Tests with Airsat1 Terminal

2.1.2.1 Objective

Communications between the Iridium Airsat1 terminal and two other communications systems used by the Canadian military were evaluated for interoperability of the systems. The two systems tested were the Inmarsat B and a Rapid Response Communications Package (RRCP) terminal using the Intelsat C-band service. The two systems are briefly described below.

2.1.2.2 Test Method

During the Northern Patrol flight between 13-17 July, calls were established between the Airsat1 terminal and an Inmarsat B terminal located at DREO. Similarly, calls between the Airsat1 terminal and the RRCP terminal were established. Items noted included the ability to establish and maintain the link and the quality of the link. Each terminal initiated calls in order to verify that the link could be setup in either direction. Connection to the PSTN by each of the terminals was established first and was used as a baseline to verify connectivity.

2.1.2.3 Test Setup

2.1.2.3.1 Inmarsat B Terminal

The Inmarsat B portable suitcase terminal provides voice, facsimile, and high speed data services at L-band. A picture of an Inmarsat B terminal with a remote antenna configuration is shown in Fig. 6. The Canadian Forces (particularly army and navy) make extensive use of this service and have numerous terminals in their inventory.

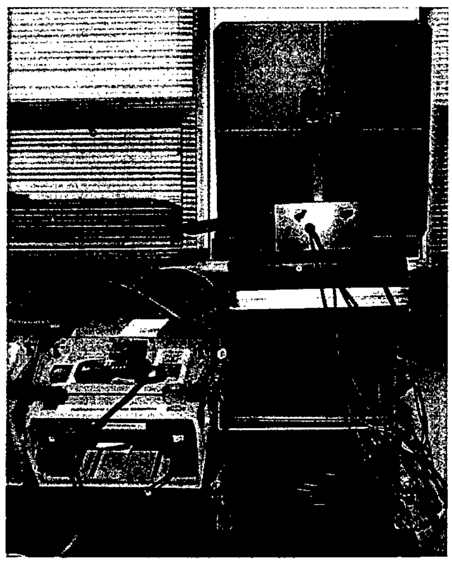


Fig. 6 Inmarsat B terminal.

To operate the terminal, the antenna must be pointed toward the ocean region satellite servicing the terminal location. Once the antenna is in position, calls can be made to and from the Inmarsat B terminal as shown in Table 3.

Direction	Dialing Sequence
PSTN to Inmarsat B	011 + (Ocean Region Code) + terminal number
Iridium ISU to Inmarsat B	00 + (Ocean Region Code) + terminal number
Inmarsat B to PSTN	00 + (Country Code) + telephone number
Inmarsat B to Iridium	00 + 8816 + 8-digit Iridium number

Table 3 Dialing procedure for calls to and from the Inmarsat B terminal

2.1.2.3.2 Rapid Response Communications Package (RRCP) Terminal

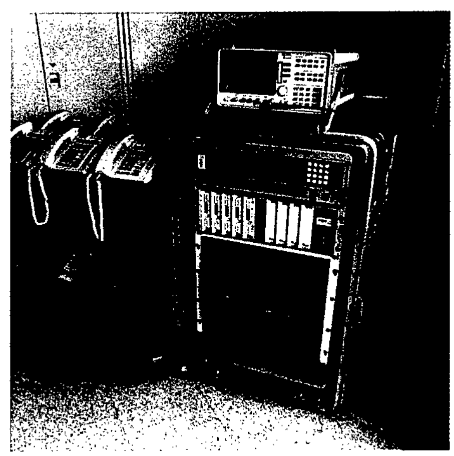
The RRCP is a prototype C- or Ku-band terminal that can use either the Intelsat C-band or Telesat Ku-band Demand Assigned Multiple Access (DAMA) telephone service. The RRCP consists of a 2.4 m antenna and a chassis capable of supporting up to 14 channel units. The RRCP is shown in Fig. 7. The RRCP provides multiple "dial-up" lines for voice, secure and non-secure facsimile, and data service at 2.4 kb/s to 16 kb/s. Service at 64 kb/s is expected in the near future. The Canadian Forces have procured two of these prototypes to be evaluated as a mid-level requirement for a small command post.

The RRCP is accessed through a PSTN switch located in Toronto, ON, Canada. Table 4 illustrates an example of dialing sequence to access a channel unit of the RRCP.

Procedure	Comment
Dial (416) 287-4070	Access PSTN switch
Listen for dial tone	
Enter authorization code	5 digit number authorization code
Listen for dial tone	
Enter 997 + Z + XXXX + YY	Z = Ocean Region XXXX = Terminal ID number YY = Channel unit number

Table 4 Sequence of steps to place a call to the RRCP terminal

(a)



(b)

Fig. 7 (a) RRCP 2.4m C-band antenna. (b) Telephony Earth Station (TES) Chassis with channel unit cards.

2.1.3 Three-way Conference Call with Iridium

2.1.3.1 Objective

The purpose of this test is to investigate the ability to establish a three-way conference call on the Iridium system.

2.1.3.2 Test Method

A conference call was set up between three PSTN terminals as a baseline for this test, (Fig. 8(a)). Three government telephone lines were used for the baseline test. Subsequently, one telephone set was replaced with an Iridium satellite phone and the conference call was re-established (Fig. 8.(b)). In this configuration, the Iridium satellite phone initiated a call to a PSTN unit. Then the PSTN called the third party and activated the three-way conference. Finally, a second Iridium phone was inserted in place of another telephone (Fig. 8.(c)). Again, the first Iridium phone called the PSTN unit. The PSTN unit subsequently called the second Iridium phone and put in place the conference call. Thus, in all three cases, the PSTN connection was used to activate the conference call. The three configurations are illustrated in Fig. 8.

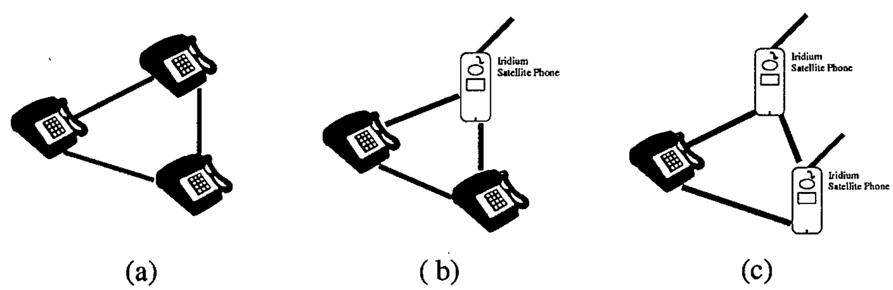


Fig. 8 Conference call configurations.

2.1.4 Propagation Delay Tests

2.1.4.1 Objective

The purpose of the propagation delay test was to measure the propagation delay of calls made over the Iridium system's voice service.

2.1.4.2 Test Method

The propagation delay test consisted of repeatedly transmitting short bursts of pure tones over an Iridium call. Tones were synchronized to a GPS receiver 1-pulse per second output and were transmitted via a speaker that was externally coupled to the microphone of one device. Received tones were picked up via a sensitive microphone that was again externally coupled to the output of the second device (either headset or speaker). Using the trace capture feature on a digital oscilloscope, the delay between the time the tone was transmitted and the time the tone was received was measured. The propagation delay for calls between a PSTN unit and an Iridium phone was measured, and subsequently, the delay for calls between two Iridium ISUs was examined. It is noted that for this test, the ISUs are co-located so that the propagation delay was measured for transmissions carried over one Iridium satellite. Tone pulses of varying duration and repetition rates were also transmitted to examine any effects of voice activation delay in the vocoder. Numerous calls were established to measure the propagation delay for the various device combinations and direction of tone transmission. In addition, a series of 100 consecutive 1 minute calls were established where the propagation delay was measured to obtain a statistical view of the delay of the system over a longer period of time.

2.1.4.3 Test Setup

A diagram of the test setup is given in Fig. 9. For the evaluation of the Iridium to PSTN link, the Iridium phone was installed in the desktop unit with an external mount antenna. For the Iridium to Iridium test, one Iridium phone was installed in the desktop unit while the other employed the satellite antenna. A pure tone of 550 Hz was selected for the tests. Tone pulses varied between 200ms to 800ms and were repeated at a 1 Hz rate. As mentioned above, the speaker and microphone used to transmit and receive the tones through the Iridium system were externally coupled to the devices under test.

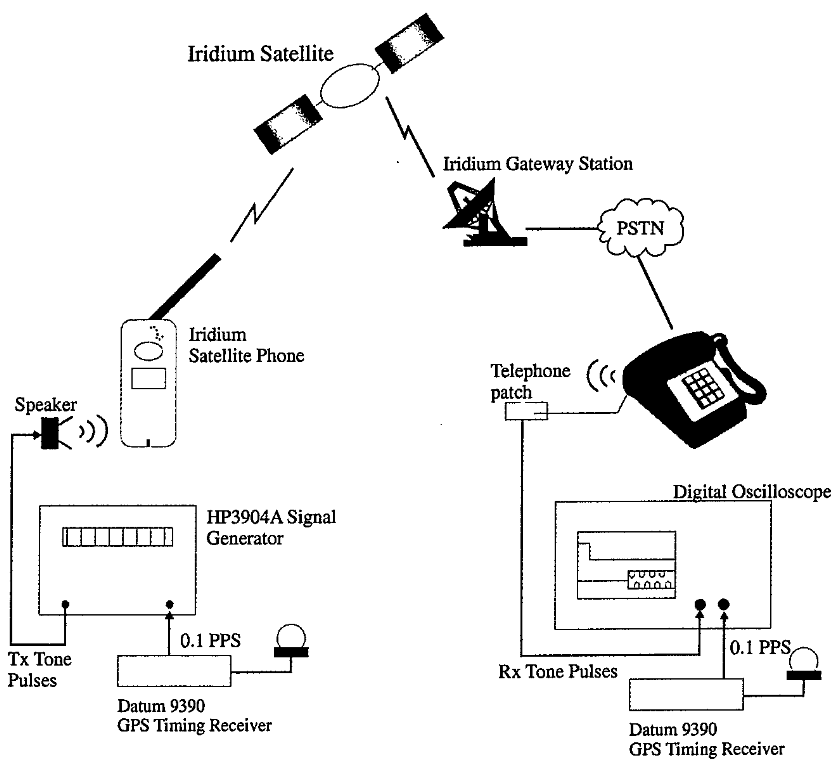


Fig. 9 Propagation delay test setup for Iridium-PSTN call.

2.2 Iridium Paging Tests

2.2.1 "Follow-me" Messaging

2.2.1.1 Objective

There are two parts to the messaging trials. The first part is to verify the "Follow-me" messaging feature of the Iridium satellite personal communications system. The second, is to examine the *Message Destination* and *Notification Destination* user option settings.

2.2.1.2 Test Method

A single test was used to verify the operation of the "Follow-me" messaging feature. The test consisted of de-activating "Follow-me" messaging and manually setting the active MDAs of the pager. A text message was sent to the pager with the incorrect MDA as well as the correct MDA. Subsequently, "Follow-me" messaging was activated. The MDA of the pager was set to one that is outside the location of the pager. A text message was sent to the pager before and after the phone was turned on to re-register on the network. It is noted that the phone was last registered in an MDA outside the location of the pager at the time of the test.

To examine the *Message Destination* and *Notification Destination* options, a set of five email messages was sent to both the pager and the phone for a total of 10 messages. Messages were sent with at least a one-minute delay between each email message. Subsequently, two voice mails were sent to both the pager and the phone. A record was kept of whether the message was received and if so, on which device it was received. This procedure was performed for most combinations of *Message Destination* and *Notification Destination* user option settings with "Follow-me" messaging de-activated.

For these tests, the user option settings were changed via the Iridium Satellite Messaging Centre by calling 1-888-588-2456 and following the procedure described in Section 1.2.3.1 and Section 1.2.3.2. In addition, to leave a voice mail for the phone or the pager, the satellite messaging centre was used again rather than dialing directly to the phone or pager. Once the user options were established, a five-minute delay was observed before sending the first email message to allow settings to take effect.

2.2.1.3 Test Setup

For the examination of message options a Motorola Iridium satellite phone was set up with the external mount antenna and desktop cradle and was powered on. A corresponding Iridium pager that is "bundled" or linked with the satellite phone was located about 1 km away on an office desk. The desk is located about 5m away from a west-facing window. The following table (Table 5) describes the user option settings that are of interest in this test.

Message Destination	*Notification Destination*
Pager	Disabled
Mobile Phone	Pager
Both	Mobile Phone
	Both

Table 5 Iridium user options examined for text messaging tests

An example of a sample set of messages would consist of 5 email messages to the pager, 5 email messages to the phone, 2 voice mail messages to the pager mailbox, and 2 voice mail messages to the phone mailbox. This sample set would be transmitted for *Message Destination* set to pager, and *Notification Destination* set to pager. The sample is repeated for combinations of settings for the two user options.

3.0 Trials Results and Discussion

3.1 Iridium Satellite Phone Test Results

3.1.1 ISU to ISU and to Airsat1 Terminal Performance at Northern Latitudes

Several calls were established between CFB Alert and DREO for Iridium to PSTN and Iridium to Iridium configurations. Call duration ranged between 5 and 20 minutes with very good voice quality and few call drops. The propagation delay of the voice signal is noticeable and if users are not accustomed to it, the delay may impact on communications effectiveness (i.e. having to repeat what was said). Abbreviated MRT results proved to be consistent with previous intelligibility tests carried out for the Iridium voice service as reported in [4]. Again, intelligibility was slightly worse with a female speaker.

Voice trials between the Iridium ISU and Airsat1 terminal showed positive results with calls of up to 15 minutes in duration being established. Calls between PSTN and Airsat1 were also evaluated. Voice quality was considered to be very good despite the noticeable presence of background noise from the aircraft. The abbreviated MRT results were between 80% and 95% which is consistent with previous tests.

Text messages sent via email to the Airsat1 terminal were received successfully during the trial.

3.1.2 Performance between Airsat1, RRCP and InmarsatB

Calls were successfully established between the Airsat1 terminal and the RRCP terminal with the Airsat1 terminal initiating the calls. It was observed that voice quality was very good between the two systems. It is noted that the Intelsat service used by the RRCP is accessed through PSTN. The dialing plan subscribed to by the RRCP used in the test only permitted calls to North American numbers and thus, was not able to initiate a call to the Airsat1 terminal which is identified by a number with an international prefix.

Calls between the Airsat1 terminal and the InmarsatB terminal were successfully established. However, calls were usually dropped after 2 minutes. It is unclear whether there is an interface problem between the two systems. It is noted that there are airtime rates listed for Airsat1 to Inmarsat calls at $6.99 per minute [2].

3.1.3 Three-way Conference Call Result

Three-way conference calls were successfully established for all three configurations of PSTN units and Iridium satellite phones. In general, the quality of the link was the same as a call between two devices. A slight decrease in volume was observed when the third party was added to the call. Voice intelligibility was equivalent to that of a simple Iridium call with some garbling of speech noted. As in the initial DREO voice evaluation [4], the delay is noticeable by the user as well as the dropping off of the first syllable of phrases.

3.1.4 Propagation Delay Test Results

Fig. 10 shows an example of the propagation delay for a call established between an Iridium satellite phone and a PSTN phone. The top trace in Fig. 10 shows the transmitted tone pulses via the Iridium phone. In this example, a 600ms pulse is used. The bottom trace shows the received pulses from the PSTN phone. Cursors at t_1 and t_2 mark the start of a transmitted pulse and the start of the received pulse respectively. The propagation delay ($\Delta t = t_2 - t_1$) for an Iridium-to-PSTN call measured between 280 ms and 500 ms.

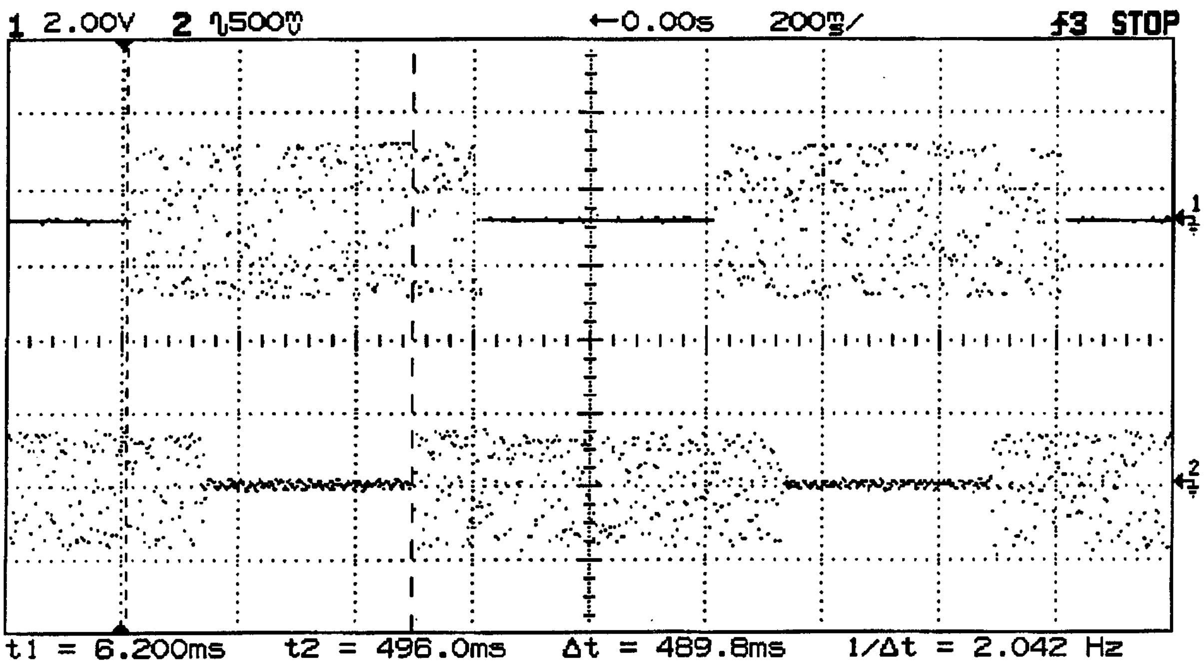


Fig. 10 Propagation delay measurement for Iridium-PSTN call using 550Hz, 600ms tone.

Fig. 11 shows a typical propagation delay measurement for calls between two Iridium ISUs. Again, the top trace shows a transmitted pulse with the cursor located at the start of the pulse, t_1. The bottom trace shows the received pulse on the Iridium phone which was picked up by the sensitive microphone. The cursor positioned at the start of the received pulse is located at time t_2. The range of propagation delays ($\Delta t = t_2 - t_1$) was measured between 200 ms and 350 ms. As mentioned above, the Iridium phones are co-located for the propagation delay tests. Thus, the shorter delays observed for Iridium-Iridium calls can be attributed to the signal travelling only to the satellite passing overhead and back. The Iridium-PSTN call consists of the signal being routed back to the gateway and subsequently routed through the PSTN infrastructure. In both cases, however, the vocoder processing delay can introduce a difference in propagation delay of up to 100ms [5].

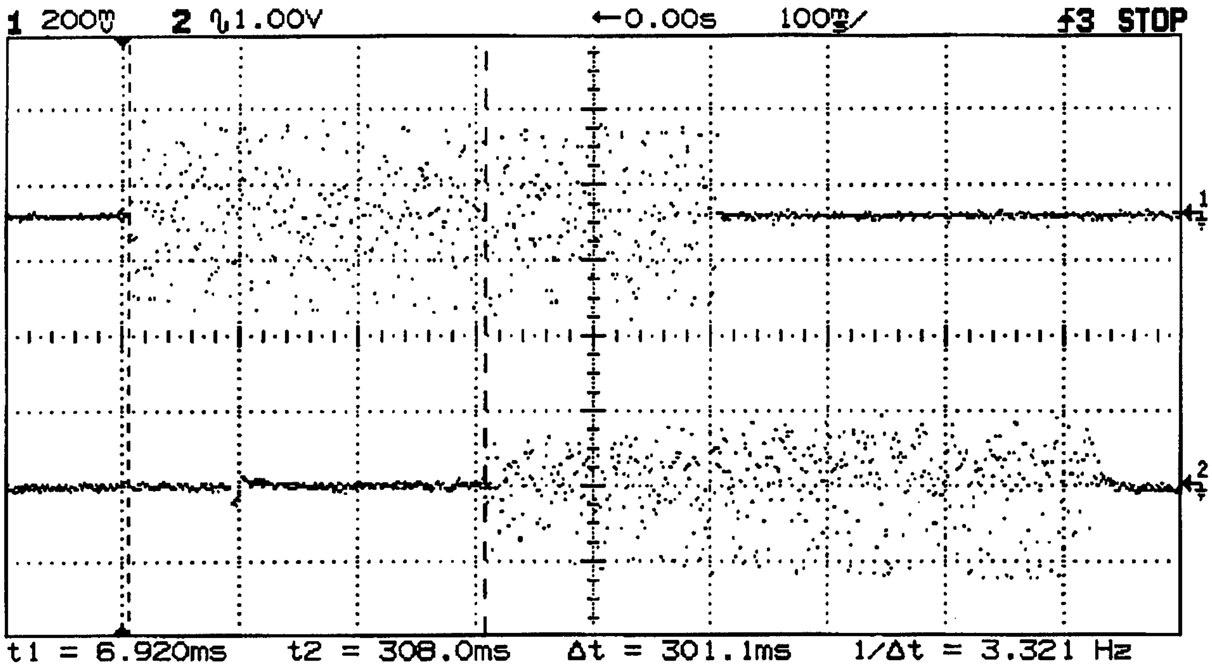


Fig. 11 Propagation delay measurement for Iridium-Iridium call using 550Hz, 500ms tone.

To obtain a more statistical view of the propagation delay over time, a series of measurements were made, at 1-minute intervals, of the propagation delay over a 100 minute period. These measurements were made over Iridium-to-PSTN calls where the tone was injected into the PSTN phone patch and the received signal is recorded from the desktop unit speaker. In [6], a theoretical value for the delay was calculated to be in the range of 100ms for a point-to-point link. The theoretical value takes into account delays due to signal propagation, codec processing, assembly and disassembly of packets, and switching and buffering operations. However, the histogram shown in Fig. 12 shows that the propagation delay was generally measured to be between 450ms and 500ms. This large discrepancy is unexplainable without further knowledge of the Iridium system.

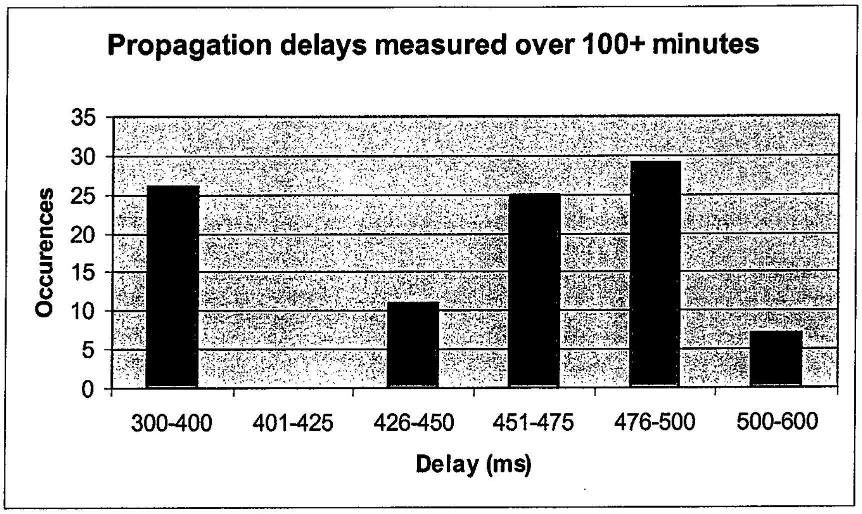


Fig. 12 Histogram of propagation delays measured over a period of 100 consecutive minutes.

3.2 Iridium Messaging Test Results

3.2.1 "Follow-me" and Messaging Options

A summary log of the text messaging test results is included in Appendix B. For the *Message Destination*, it was verified that text messages are delivered correctly to the pager, phone, or both, depending on the user selection. Similarly, for voice mail, a message was received on the pager, phone, or both, depending on the user's selection of the *Notification Destination*. It is noted that with the phone and pager under test being bundled, it was found that the address to which the message (text or voice) is being sent was irrelevant. A bundled phone and pager share the same mailbox for text and voice messages. The message centre refers to the mailbox by the pager number regardless of whether you enter the pager number or the satellite phone number. Hence for a bundled phone and pager, the user options solely dictate where messages are delivered.

It was observed that when both the pager and phone are selected to receive text or voice messages, a "duplicate" message indicator appeared in the pager entry. In addition, for voice mail notification, only one entry was shown on the pager for multiple voice mail messages, whereas separate messages are received on the phone for each voice mail message. The message to notify the user of a pending voice mail consisted of the phone number for the message centre.

It was noted that although an option is available to "disable message notification" under the notifications menu, the actual effect is to disable **both** receipt of text messages and voice mail notification. Text and voice messages are stored in the user's mailbox. In this configuration, when the user checks the mailbox for messages, text messages can be resent and received without changing the notification and message destination options. One advantage of disabling message notification may be for situations where a user wishes to only check for messages occasionally and to download all messages at a particular time.

It was observed that with "Follow-me" messaging de-activated, messages were delivered to the active MDAs set through the message centre or through the website paging coverage administration. Thus, messages were received only when the active MDAs included one corresponding to the area where the pager was located. Once "Follow-me" messaging was activated, the MDA corresponding to where the phone is last registered overrides the active MDAs and the result is that the pager must be located in the area where the phone is last registered to be able to receive messages.

4.0 Summary and Conclusions

The additional voice service tests described in this document were carried out at DREO between June and November 1999. Tests included voice service at high latitudes, voice tests of Iridium ISUs with an Airsat1 terminal and voice service between Airsat1 and other communications systems used in the Canadian Forces. As well, the three-way conferencing capability over Iridium, the Iridium messaging service, and propagation delay measurements over the voice circuit were examined.

Good quality voice communications were achieved between Iridium, Airsat1, and PSTN combinations at high latitudes. Abbreviated MRTs showed intelligibility results between 80% and 95%, which is consistent with voice service tests carried out previously. As a result of the high latitude tests, CFB Alert has acquired an Iridium phone with the desktop unit and external mount antenna. The Iridium system will provide CFB Alert with a readily available communications resource for normal day-to-day operations.

Calls were also established between the Airsat1 terminal and Iridium, InmarsatB, and RRCP terminals. For Airsat1-InmarsatB links, calls were not maintained for more than a couple of minutes at the most. Further work may be required to investigate any interface issues between the Airsat1 and InmarsatB terminals. Interoperability of these systems for voice communications is considered to be of great benefit to the Canadian Forces who currently have Inmarsat and RRCP terminals in their inventory.

The ability to establish a three-way conference call was successfully demonstrated using a PSTN connection with two Iridium satellite phones. It is noted that the conference call was established by the PSTN phone facility and not by Iridium. However, Iridium has advertised in their user's guide that with their world calling card, up to 4 parties can be connected over Iridium.

The message options associated with a bundled satellite phone and pager were examined. *Message Destination* and *Notification Destination* options allow the user to select whether text messages and voice mail notification messages, respectively, are delivered to the pager, phone, or both the phone and pager. One possible application would be for a user to set up the options for all messages to be directed to the pager. The user then has the option to activate the phone only when he needs to place a call or to update the MDA of the pager, thereby conserving the battery life of the phone. One option that was misleading was the "*Disable Message Notification*" option. This option was listed under the *Notification Destination* menu. It was originally thought that this option disabled the notification of voice mail. However, the effect of disabling message notification was to disable both the delivery of text messages and voice mail notification messages to the pager. Messages to the pager or phone were stored in the mailbox. Another feature called "Follow-me" messaging was found to be an advantage with a bundled phone and pager as it provided a "roaming" capability such that the user did not have to know which MDA to set for his pager.

Again, one of the drawbacks of the Iridium system is the inability to review what user options have been selected for the phone and pager. This means that if the user does not remember the current settings, he has to re-enter the settings by going through all the menus again. Certainly, being able to view the user option settings on a browser or to list them on the phone would be a great advantage.

Propagation delay tests were carried over the Iridium voice circuits for Iridium-Iridium and Iridium-PSTN calls. For Iridium-Iridium calls, the propagation delay measured between 200ms and 350ms. For Iridium-PSTN calls, the delay was observed to be generally between 450ms and 500ms. However, delays of less than 400ms were also measured for Iridium-PSTN calls. In addition to signal propagation, delays may be attributed to voice activation, vocoder processing and call or network queuing. It is noted that for Iridium-Iridium calls, the two Iridium ISUs were co-located. Thus, it is expected that the transmitted signal would have traveled to the satellite passing overhead and back to the receiving phone without being routed to another satellite. This would explain the shorter delays measured for Iridium-to-Iridium links vs. Iridium-to-PSTN links. Further work is planned to investigate the propagation delay for links over longer distances.

5.0 References

[1] www.iridium.com

[2] www.bendixking.com/axs/satcom/index.html

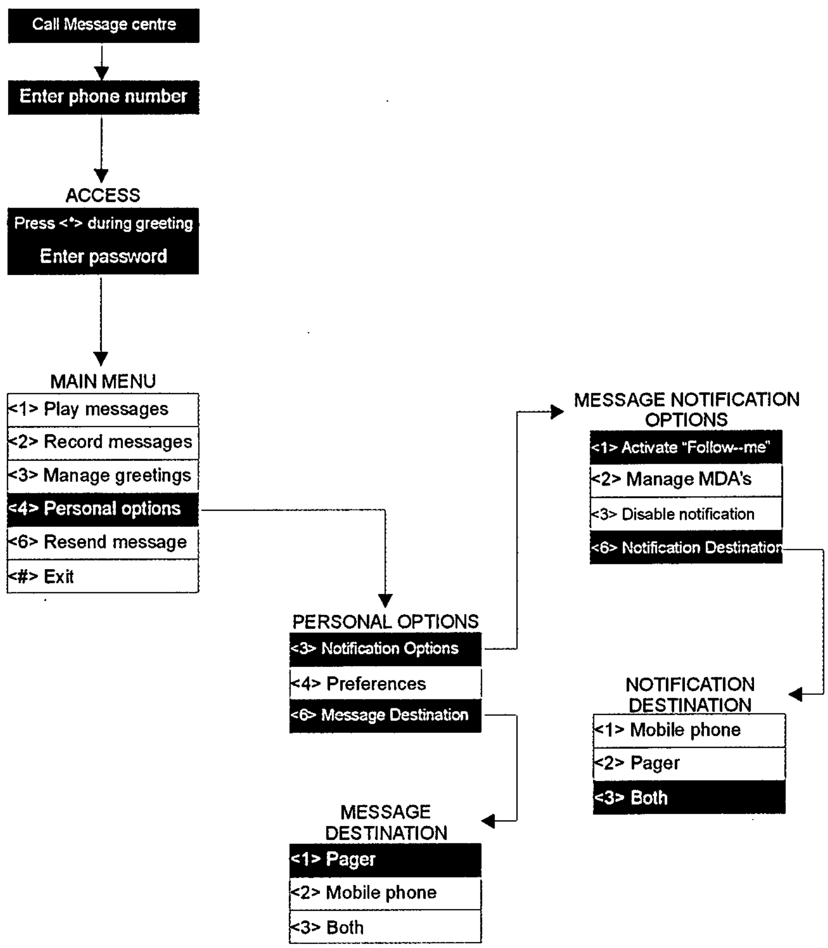
[3] C. Tom, L. Wagner, "*Evaluation of Iridium Paging Services for Military Applications*", DREO TM-087, Ottawa, Canada, August 1999.

[4] C. Tom, L. Wagner, "*Evaluation of Iridium Satellite Phone Voice Services for Military Applications*", DREO TM-086, Ottawa, Canada, September 1999.

[5] APCO/NASTD/Fed Project 25 Vocoder Description, December 1 1992.

[6] M. Werner, A. Jahn, E. Lutz, A. Böttcher, "*Analysis of System Parameters for LEO/ICO-Satellite Communications Networks*", IEEE Journal on Selected Areas in Communications, Vol. 13, no.2, pp.371-381, February 1995.

APPENDIX A



Subset of user options menus for the Iridium system [1]

APPENDIX B

Iridium Messaging Options Log

Msg Destination	Notf Destination	Text Messages		Voice Messages	
		Rec'd by ph	Rec'd by pg	Rec'd by ph	Rec'd by pg
pager	phone	0%	90%	100%	0%
pager	pager	0%	100%	0%	100%
pager	both	0%	90%	100%	100%
pager	disabled	0%	90%(1)	0%	0%
phone	pager	100%	0%	0%	100%
phone	phone	100%	0%	100%	0%
phone	both	100%	0%	100%	100%
phone	disabled				
both	phone	100%	100%	75%	0%
both	pager	100%	90%	0%	100%
both	both	100%	90%	100%	100%
both	disabled	100%(1)	100%(1)	0%	0%
(1) Messages were received after being resent from message centre, settings unchanged					

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Further Examination of Iridium Satellite Phone and Pager for Military Use (U)

4. AUTHORS (Last name, first name, middle initial)

Tom, Caroline, and Lambert, James, D.

5. DATE OF PUBLICATION (month and year of publication of document) January 2000	6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 41	6b. NO. OF REFS (total cited in document) 6

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

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10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DREO Technical Memorandum 2000-084	10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

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The Iridium satellite-based personal communications system (PCS) has been offering voice and messaging services since November 1998 and March 1999 respectively. With its interconnected constellation of 66 low earth orbit (LEO) satellites, Iridium is capable of providing continuous communications anywhere in the world. This Technical Memorandum describes further evaluations of the Iridium system carried out by the Military Satellite Communications group at Defence Research Establishment Ottawa (DREO). Evaluations include additional voice service test at high latitudes, voice service tests with an Airsat1 terminal, messaging service evaluation, three-way conference calling over Iridium, and propagation delay tests over the voice circuit.

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Satellite-based Personal Communications System
PCS
Iridium
Low earth orbit
LEO
Voice service
Messaging service
Evaluation